RESEARCH DEPARTMENT

Image orthicon investigations: the measurement of vertical resolution

RESEARCH REPORT No. T-100/5

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IMAGE ORTHICON INVESTIGATIONS: THE MEASUREMENT OF VERTICAL RESOLUTION

Research Report No. T-100/5

(1964/61)

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IMAGE ORTHICON INVESTIGATIONS:
THE MEASUREMENT OF VERTICAL RESOLUTION

SUMMARY

This report describes a technique for the accurate measurement of vertical resolution in a television camera and also gives the results of investigations into the vertical resolution of the 4½ in. image orthicon type P. 822, (manufactured by the English Electric Valve Co.). Measurements have been made in order to determine the extent to which a variation of operating conditions influences the performance of the tube in this respect.

1. INTRODUCTION

The results of measurements of the vertical resolution of the image orthicon[1,2] have already been published but only one of these papers has referred to the 4½ in. version of this camera tube, and in this case the operation was limited to one line-scanning standard (405) only. In this series of measurements, the vertical resolution has been measured on several different line-scanning standards, in order to determine any changes in performance which may be observed.

The basic method of measurement was similar to that used by other workers, but some refinements were added in order to enable more precise measurements to be made. These were necessary since in some cases only small changes in resolution were being investigated. Some investigations were also carried out in order to determine how each of the factors involved in a change of scanning standard affected the resolution. Measurements were confined to two tubes (both being second-grade due to blemishes) since the length of time for which they were exposed to the image of a high-contrast transparency was necessarily considerable, and this resulted in permanent ‘burning’ of the target. There are, inevitably, variations in the performance of tubes, but it was considered that the change of resolution encountered with change of operating conditions in these experiments would be representative of the changes occurring with all tubes.

In an appendix, the effect upon the vertical resolution of an overlap of successive scanning lines is considered in terms of the ‘beam profile’.

2. DEFINITION OF VERTICAL RESOLUTION

If a television camera is focused on a test transparency in which a large uniform white area is separated from a large black area by a sharp horizontal boundary, the vertical resolution of the camera can be measured in terms of its ability to resolve this boundary.

There are several possible definitions for vertical resolution; for example, it might be stated as the number of picture lines required by the camera to portray completely such a sharp transition. This has the disadvantage of being measurable only in quanta of one line, and is thus unsuitable for expressing the results of measurements precisely.

A more satisfactory method results when attention is concentrated on one line of the television picture. The output of the camera tube may be measured for a large number of positions of this particular line relative to the image of a horizontally-disposed transition in a scene presented to the camera. If the tube output signal is then plotted as a function of this variable the resulting curve is a profile of the transition as portrayed by the camera for all positions of the transition relative to the scanning lines. The vertical resolution of the camera tube may then be defined as the relative shift in the field direction required to cause the output of a certain scanning line to change from 10% to 90% of the total change in output caused by the transition in the scene. The figures 10% and 90% are arbitrary, but convenient.

The relative shift may be expressed in three ways:

(i) In units of line spacing at the particular standard used.

(ii) As a fraction of the total picture height.

(iii) As the number of active lines in an ideal scanning system of equivalent vertical resolution.

In order to illustrate these three methods, consider a tube operating on 405 lines (377 active lines); its vertical resolution could be expressed as, for example:

(i) 1·1 lines.

(ii) $\frac{1 \cdot 1}{377} = 2 \cdot 92 \, . \, 10^{-3}$ of total picture height.

(iii) $\frac{377}{1 \cdot 1} = 343$ lines.

Each of these three methods has merit, and the most appropriate one in a particular context will be used in this report.

When an overshoot is present in the portrayal of a boundary edge, the 10% and 90% figures will refer to the maximum change in signal amplitude, including the overshoot; this has been done since the total amplitude change is precisely measurable, but when the overshoot has long-term effects, the amplitude of the change (excluding the overshoot) is difficult to measure.

3. APPARATUS USED FOR THE MEASUREMENT OF VERTICAL RESOLUTION

In Section 2 it has been shown that the measurement will involve relative movement between the image charge pattern on the target and the raster traced by the scanning lines. The relative movements required are small, and can be achieved in several ways. The possibilities considered were:

(i) Moving the illiminated test transparency vertically by the use of a micrometer device to produce and measure the movement.

(ii) Moving the image of the test transparency on the tube by interposing a reflecting surface or refracting medium between the transparency and the lens: this surface could then be rotated to produce the required shift.

(iii) Moving the scanning raster, rather than the image, by passing a calibrated and continuously variable shift current through the field-scan coils of the camera.

Method (i) suffers from the disadvantage that it requires elaborate mechanical arrangements to move an inconveniently large object with sufficient precision. Method (ii) also requires precision mechanical arrangements, and might degrade the optical image of the test object. Method (iii) is simple to instrument and since it is capable of adequate accuracy, this approach was adopted.

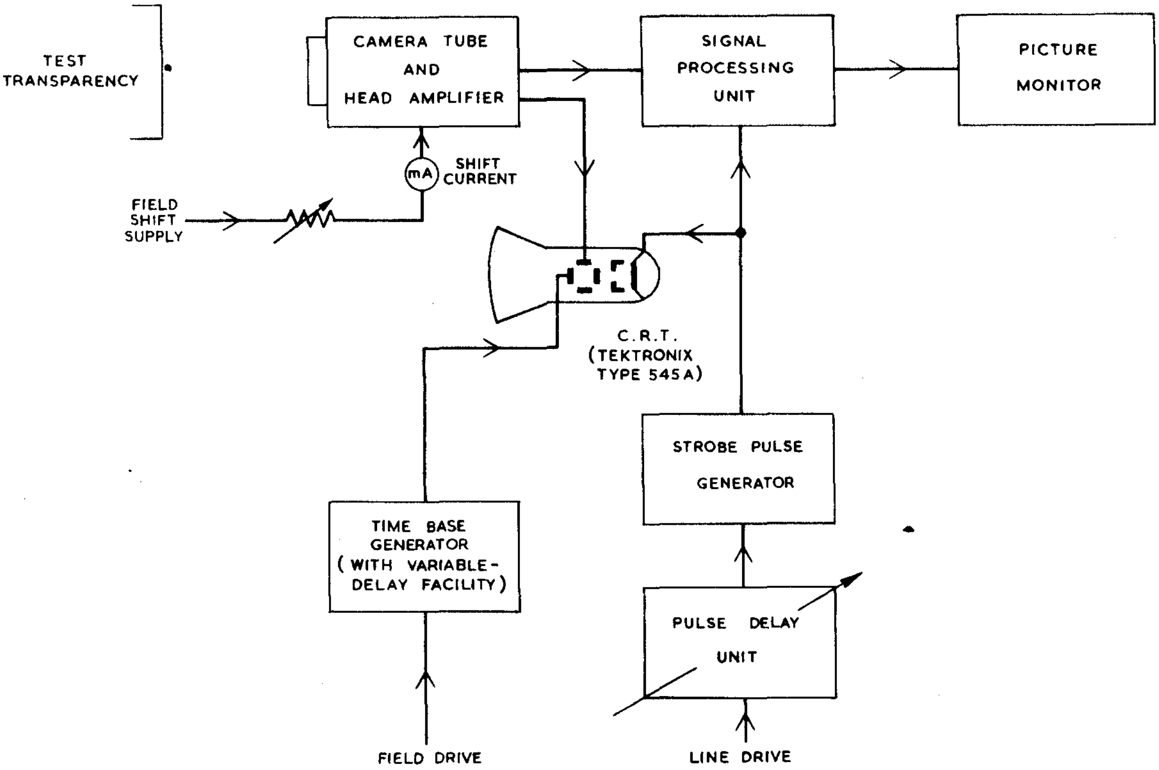

Fig. 1 - Block diagram of equipment

The equipment used for the measurements is shown in block diagram form in Fig. 1. The test transparency used is shown in Fig. 2; this will be described in more detail later. The camera and signal processing unit used were those incorporated in the camera tube test bench,[3] while the time base generator and cathode-ray tube were those contained in a Tektronix type 545A oscilloscope. The strobe pulse generator was specially constructed and produced negative-going pulses of 2 μsec duration, delayed by a controlled variable amount with respect to line drive pulses. The 2 μsec pulses were used to brighten the trace on the oscilloscope during one selected part of every line of the picture. Pulses were also introduced into the signal processing unit so as to produce a marker on the picture monitor, thus facilitating the positioning of the pulses.

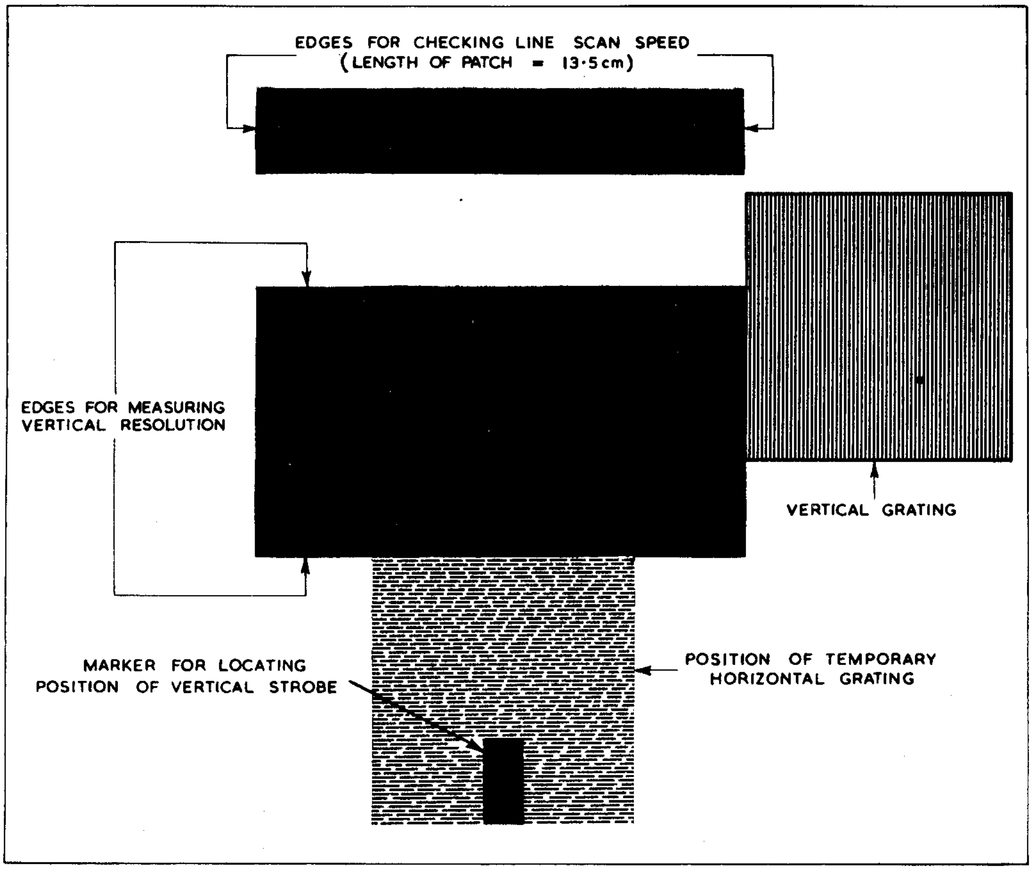
EDGES FOR CHECKING LINE SCAN SPEED
(LENGTH OF PATCH = 13·5cm)
EDGES FOR MEASURING VERTICAL RESOLUTION
VERTICAL GRATING
MARKER FOR LOCATING POSITION OF VERTICAL STROBE
POSITION OF TEMPORARY HORIZONTAL GRATING

Fig. 2 - Test transparency

The test transparency, Fig. 2, occupied about one third of the height and one third of the width of the field of view of the optical system, the remainder being in darkness. The clear background of the test transparency was illuminated with a uniform light source. The upper black patch had carefully cut left- and right-hand edges, and was used as a reference producing an output pulse from the camera tube, the duration of which could be measured as a check of the line-scan velocity. The lower large black patch had top and bottom edges which were parallel; these edges were used for the resolution measurements. The small patch at the bottom of the transparency was used as a marker point, all measurements being made on a vertical line through this point. An additional horizontal grating was added in the position shown, as and when required. The length of the reference pulse, when the camera was being operated on 405 lines, was measured and found to be 11·6 μsec, i.e. about one seventh of an active line. It was established that the lens used in the experiments was capable of resolving the equivalent of a 2,000 line raster, i.e. a black-to-white transition could be accomplished in less than 1/2000 of the picture height.

4. METHOD OF MEASUREMENT

An image of the test transparency was focused on the photocathode of the tube, and adjustments to the image section and beam focus were made until optimum output corresponding to the vertical and horizontal gratings was obtained. In the case of the horizontal grating a beat pattern was produced between the scanning lines and the grating and the focus was adjusted for maximum pattern amplitude: the grating was then removed so that measurements could be made on the lower edge of the patch. The oscilloscope was used to display a selected group of lines including the edge being measured. By using the 2 μsec pulses (See Fig. 1) to brighten the trace, a display similar to those shown in Figs. 3(a) and 3(b) was produced. This type of display is known as a ‘vertical strobe’ and represents the waveform of a vertical section down the picture.

Two series of measurements were made. In the first series the vertical resolution of the camera was examined by plotting the complete profile of its portrayal of the high-contrast edge in the test transparency. To obtain this complete profile one particular line was selected and the signal amplitude of this line was measured for a large number of values of shift current in the field scan coils. Thus, the one particular scanning line was moved by small increments past a black-to-white transition imaged upon the target, thereby producing, in effect, a vertical scan from which the vertical resolution of the camera may be determined.

Having established the shape of this profile the rather tedious process of plotting the entire curve was then simplified and only two ‘key’ points were measured: these were the field shift currents corresponding to output signal amplitudes of 10% and 90% peak signal. This was sufficient information for many purposes and had the advantage that the measurements were less vulnerable to drift since they could be made in rapid succession. Readings were taken on both the black-to-white and the white-to-black transitions. The shift current was calibrated by bringing several lines in turn to the position in which their output was at some easily recognised level.

A difficulty which arises in such measurements is that if the test pattern is imaged onto the same part of the target there will be a progressive ‘burning-in’ of the pattern which will affect the measurements. If the test pattern is frequently moved in order to avoid this effect the readings might be inconsistent as a result of variations of image-section focus or beam focus over the target area. As a compromise, all readings of one group were taken on the same part of the target, with occasional repetitions of one condition as a check on the effect of ‘burning-in’. Different series of readings, however, were taken using different parts of the target, so that the effects of ‘burning-in’ never became excessive.

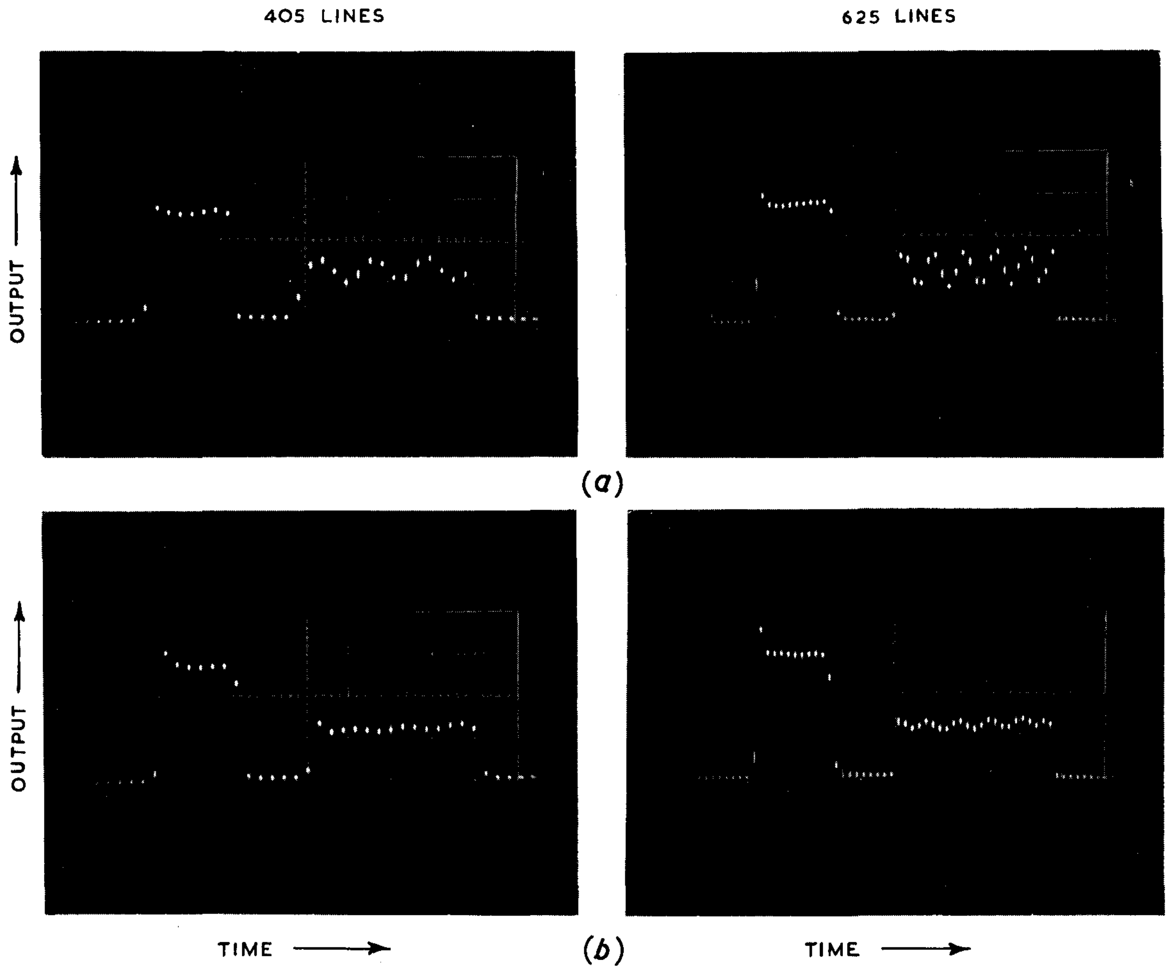

Fig. 3 - Vertical strobes of test transparency, including horizontal grating pattern, using a 2 μsec brightening pulse (one field only shown in each case)

(a) Optimum beam focus
(b) Beam focus adjusted for maximum overshoot on black-to-white transition

5. SUMMARY OF FACTORS AFFECTING VERTICAL RESOLUTION

The vertical resolution may depend on the following operating conditions:

(1) Optical focus

(2) Image-section focus

(3) Beam focus

(4) Scanning standard

(5) Scene brightness

(6) Target temperature

(7) Target-mesh potential (with respect to gun cathode)

Conditions (1) and (2) are straightforward. Condition (3) is not so straightforward since several criteria for optimum resolution exist: these are dealt with in detail in Section 6.

Condition (4) has been extensively investigated and the results are given in Sections 7 and 8.

Conditions (5) and (6) have not been investigated quantitatively; all measurements were made with the white area of the transparency exposed ½ stop above the 'knee' of the transfer characteristic and, unless otherwise stated, with the target section of the tube at 45°C.

Condition (7) was not investigated, all measurements being made under the preferred operating condition of 3·0 V above 'target cut-off' potential.

6. EFFECT OF THE BEAM FOCUS ON RESOLUTION

The investigation into the effects of small variations in the beam focus condition upon both vertical and horizontal resolution was conducted with the camera tube operating on the 405-line standard. Observations were also made on the variations of the amplitude of overshoots following transitions.

6.1. The effect of beam focus on vertical resolution

Measurements were made of the vertical resolution of both black-to-white and white-to-black transitions expressed as parts in 10^3 of the picture height for various values of wall-anode voltage from 197·5 V to 212·5 V. These results are shown in Fig. 4. The dotted curve is the average of the resolutions of the two transitions. The small difference between the sharpest transitions of the black-to-white and white-to-black cases was probably due to the two boundaries not being exactly parallel to one another so that they could not both be parallel to the scanning lines simultaneously. In a subsidiary test at a single setting of the focus control it was found that a small rotation of the transparency in one direction improved the white-to-black resolution and made the other worse than before, while a small rotation in the opposite direction made both the resolutions worse. No conclusion should, therefore, be drawn concerning the apparent small difference in resolution. When a boundary is not parallel to the scanning lines the camera output may change noticeably while the oscilloscope trace is brightened by a strobing pulse, the apparent effect being a vertical spreading of the corresponding point of the display. This gave a useful indication of the accuracy with which the transparency had been adjusted and of changes in the operating conditions in the image section of the tube which could cause a rotation of the electron image at the target.

The sharpest white-to-black transition occurs when the wall anode is at 206 V, but the sharpest black-to-white transition occurs when the wall anode is slightly lower, at 204 V. A difference in focus condition of this order of magnitude has been observed consistently but the reasons for it are not understood.

It will be seen from Figs. 3(a) and 3(b) than an overshoot is usually produced at a black-to-white transition, but not on a white-to-black transition; the amplitude of this overshoot varies with the beam focus condition and is dealt with separately in Section 6.3.

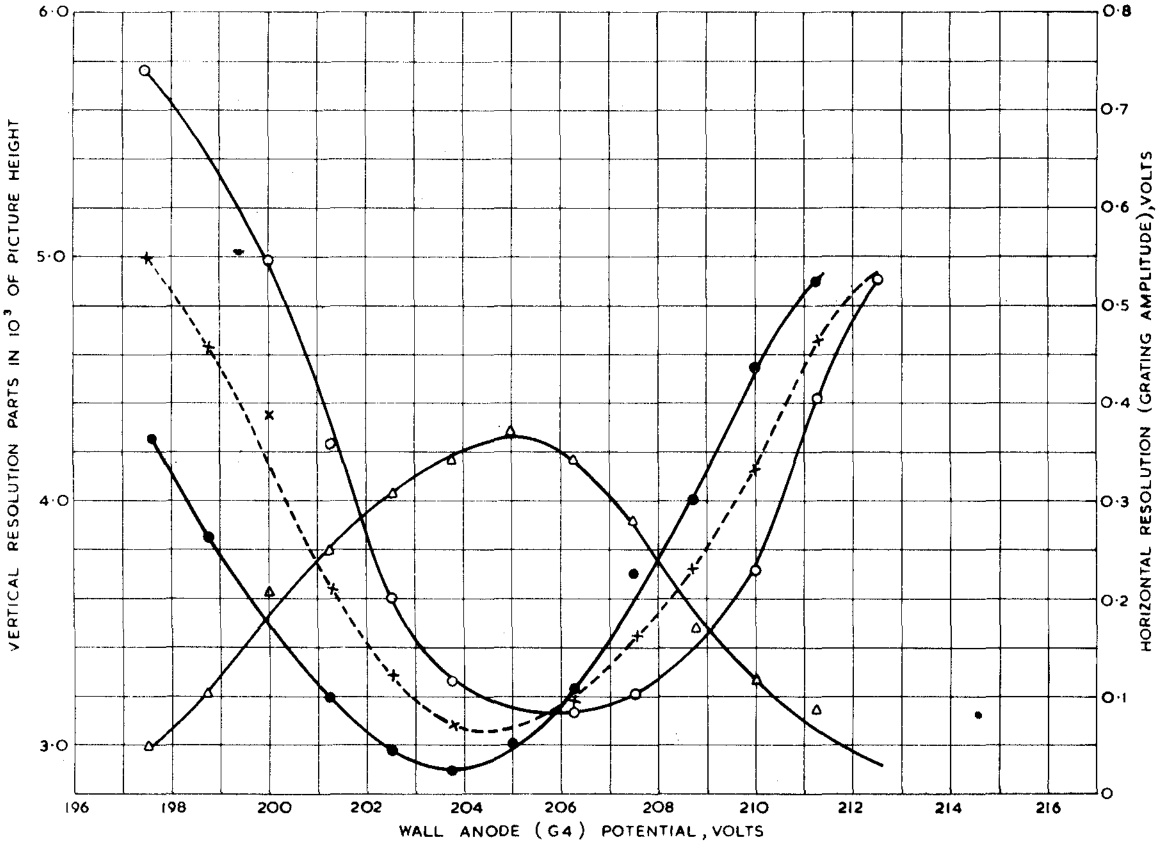

Fig. 4 - Effect of beam focus on resolution

○ Vertical resolution white-to-black
● Vertical resolution black-to-white
× Average vertical resolution
△ Horizontal resolution

6.2. The effect of beam focus on horizontal resolution

In order to investigate the variation of horizontal resolution with beam focus, a vertical grating was used to produce a high-frequency signal, the peak-to-peak value of which was compared with that due to a black-to-white transition between large areas. These results are also shown in Fig. 4 and reveal an optimum at approximately 205 V. Because of the presence of noise it was not possible to measure the times of rise and fall of the waveform with sufficient accuracy to distinguish any anomalies between black-to-white and white-to-black transitions. In the vertical resolution measurements there was always some scatter in the results caused principally by the difficulty of maintaining a consistent focusing condition. Two methods of setting the focus were used, both of which proved fairly satisfactory. In one case the vertical grating was used and the tube focused for maximum signal amplitude while observing the waveform of one particular line. In the second case a horizontal grating was placed temporarily in front of the test transparency on the line of the vertical strobe. The resulting beat pattern is shown in the right-hand portions of the photographs of Fig. 3(a) (during one field only). With this method the noise could be reduced appreciably by low-pass filtering without lessening the accuracy of the measurement and the focus condition was taken as that for which the beat pattern had a maximum amplitude. The procedure was, however, complicated by the fact that changes in focus changed the position of the beat pattern, and the vertical shift had to be re-adjusted to ensure that at least one line-sampling point occurred at the peak of a beat cycle.

6.3. Amplitude of signal overshoot at transitions

It was observed that, in the case of the black-to-white transition, an overshoot is usually produced and the conditions leading to the production of this overshoot were investigated.

The table below shows the magnitude of the overshoot under various conditions of operation, all peaks having been normalized to unity.

TABLE 1

Overshoot on black-to-white transition as a percentage of the total amplitude

ILLUMINATION* AT PHOTOCATHODE lm/sq.ft	Lux	TARGET TEMPERATURE 47°C OVERSHOOT 405 lines	625 lines	TARGET TEMPERATURE 26°C OVERSHOOT 405 lines	625 lines
0·017	0·18	6·5%	6·5%	0	0
0·09	0·98	10·5%	12·0%	10·5%	9·0%
1·34	14·5	9·0%	9·0%	8·0%	10·0%

It will be seen that the overshoot increases with light level under all conditions up to half a stop above the $\gamma = 0{\cdot}5$ point, corresponding to an illumination of 0·09 lm/sq.ft (0·98 lux), and then remains reasonably constant. The only condition in which it does not appear is at low light level and low temperature.

The test pattern was of the form shown in Fig. 2, with the horizontal grating added. Fig. 3(a) shows the vertical waveform of the pattern when reproduced with 405- and 625-line systems (only one field is shown in each case). The exposure for the white area was at half a stop above the $\gamma = 0{\cdot}5$ point, and the tube was at normal operating temperature. The overshoot on the black-to-white transition is clearly visible.

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* Due to the clear portions of the test transparency, Fig. 2.

The magnitude of the overshoot on each system is similar, but more visible in the case of the 625-line standard owing to the closer spacing of the lines. In each case the beam focus was set to give maximum output of the horizontal grating pattern. It will also be noticed that the amplitude of the grating pattern is greater on the 625-line standard, and it will be shown in Section 7 of this report that the vertical resolution of the tube is somewhat greater when operating on this standard.

Overshoots on the edges have in the past been attributed[1,2] to increased effective target-to-mesh capacitance at the edges of a bright area. This, however, does not appear to be a complete explanation because it is found that defocusing the beam (decreasing wall-anode voltage) produces a greatly increased overshoot. In Fig. 3(b), it will be seen that there has been considerable defocusing of the grating yet there is a large increase in the overshoot. The overshoot is probably slightly greater on a 625-line standard and is rather more sharp.

It would appear that the production of the overshoot is probably a combination of several effects which include those due to beam pulling and variations of beam landing conditions.

7. VARIATION OF VERTICAL RESOLUTION WITH SCANNING STANDARD

In this case all focus controls were adjusted for the best resolution of the vertical grating pattern. The exposure used was such that the white area surrounding the black patch was exposed to the $\gamma = 0{\cdot}5$ point on the contrast-law characteristic. In order to examine the progressive change in resolution with standard, some unconventional scanning standards were used in addition to normal standards. The standards were:

TABLE 2
Interlaced standards used in vertical resolution measurements

SCANNING STANDARD (LINES PER PICTURE)	NUMBER OF ACTIVE LINES PER PICTURE
819 lines, 50 fields	737
705 " "	657
625 " "	585
525 " "	497
405 " "	377
351 " "	327
301 " "	281
189 " "	177

Results obtained using the American standard of 525 lines 60 fields were separately compared with those obtained using the 405-line standard.

The results for two different tubes are given in Tables 3 and 4. Each result is the average of measurements made on the white-to-black and the black-to-white edges of the test transparency, Fig. 2. Only the 10% and 90% points were measured.

TABLE 3

Results of vertical resolution measurements using the standards of Table 2: Tube 'A'

NUMBER OF ACTIVE LINES PER PICTURE	RESOLUTION	
	IN TERMS OF A FRACTION OF THE PICTURE HEIGHT	IN TERMS OF AN EFFECTIVE NUMBER OF LINES
737	$2{\cdot}67 \,.\, 10^{-3}$	375
657	$2{\cdot}77 \,.\, 10^{-3}$	361
585	$2{\cdot}78 \,.\, 10^{-3}$	360
497	$2{\cdot}75 \,.\, 10^{-3}$	364
377	$3{\cdot}04 \,.\, 10^{-3}$	329
327	$3{\cdot}32 \,.\, 10^{-3}$	301
281	$3{\cdot}62 \,.\, 10^{-3}$	276
177	$4{\cdot}97 \,.\, 10^{-3}$	201

These results are shown graphically in Fig. 5.

TABLE 4

Results of vertical resolution measurements using the standards of Table 2: Tube 'B'

NUMBER OF ACTIVE LINES PER PICTURE	RESOLUTION	
	IN TERMS OF A FRACTION OF THE PICTURE HEIGHT	IN TERMS OF AN EFFECTIVE NUMBER OF LINES
737	$2{\cdot}52 \,.\, 10^{-3}$	397
657	$2{\cdot}78 \,.\, 10^{-3}$	360
585	$2{\cdot}79 \,.\, 10^{-3}$	358
497	$2{\cdot}86 \,.\, 10^{-3}$	350
377	$2{\cdot}94 \,.\, 10^{-3}$	340
327	N.M.	N.M.
281	$3{\cdot}27 \,.\, 10^{-3}$	306
177	$5{\cdot}91 \,.\, 10^{-3}$	169

N.M. = Not Measured

These results are shown graphically in Fig. 6.

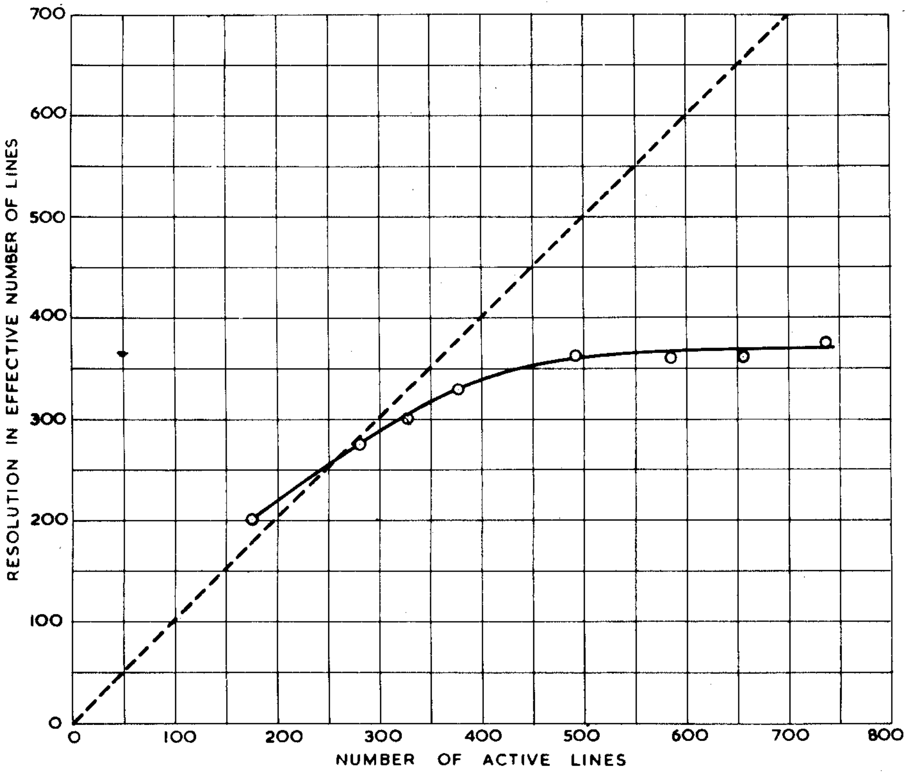

Fig. 5 - Variation of vertical resolution with scanning standard - Tube 'A'

——— Tube performance ‒ ‒ ‒ Desirable performance

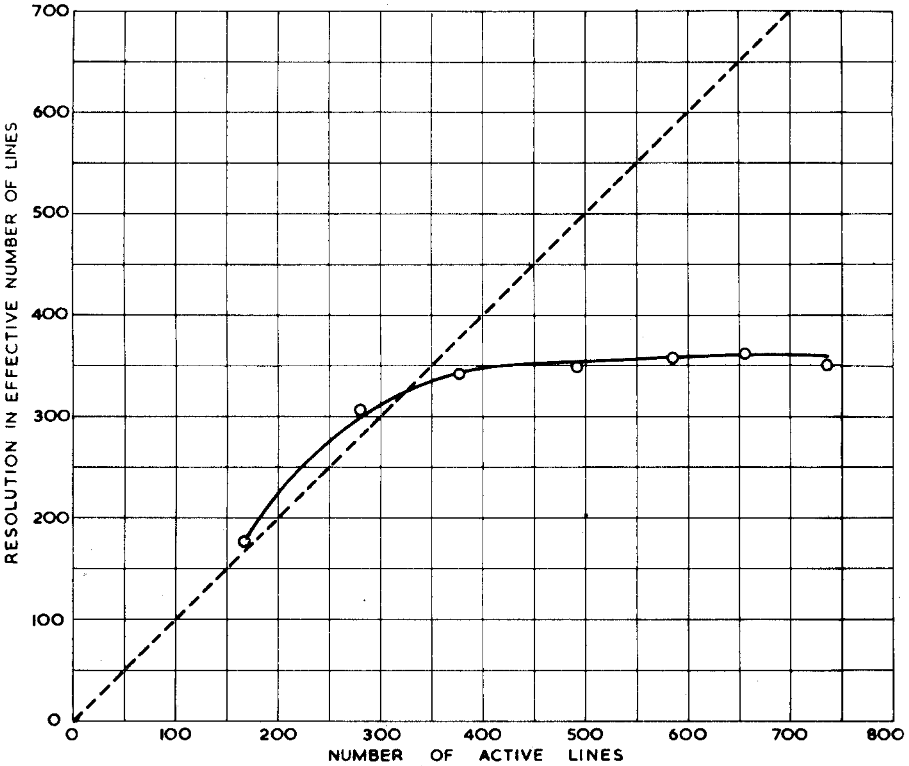

Fig. 6 - Variation of vertical resolution with scanning standard - Tube 'B'

——— Tube performance ‒ ‒ ‒ Desirable performance

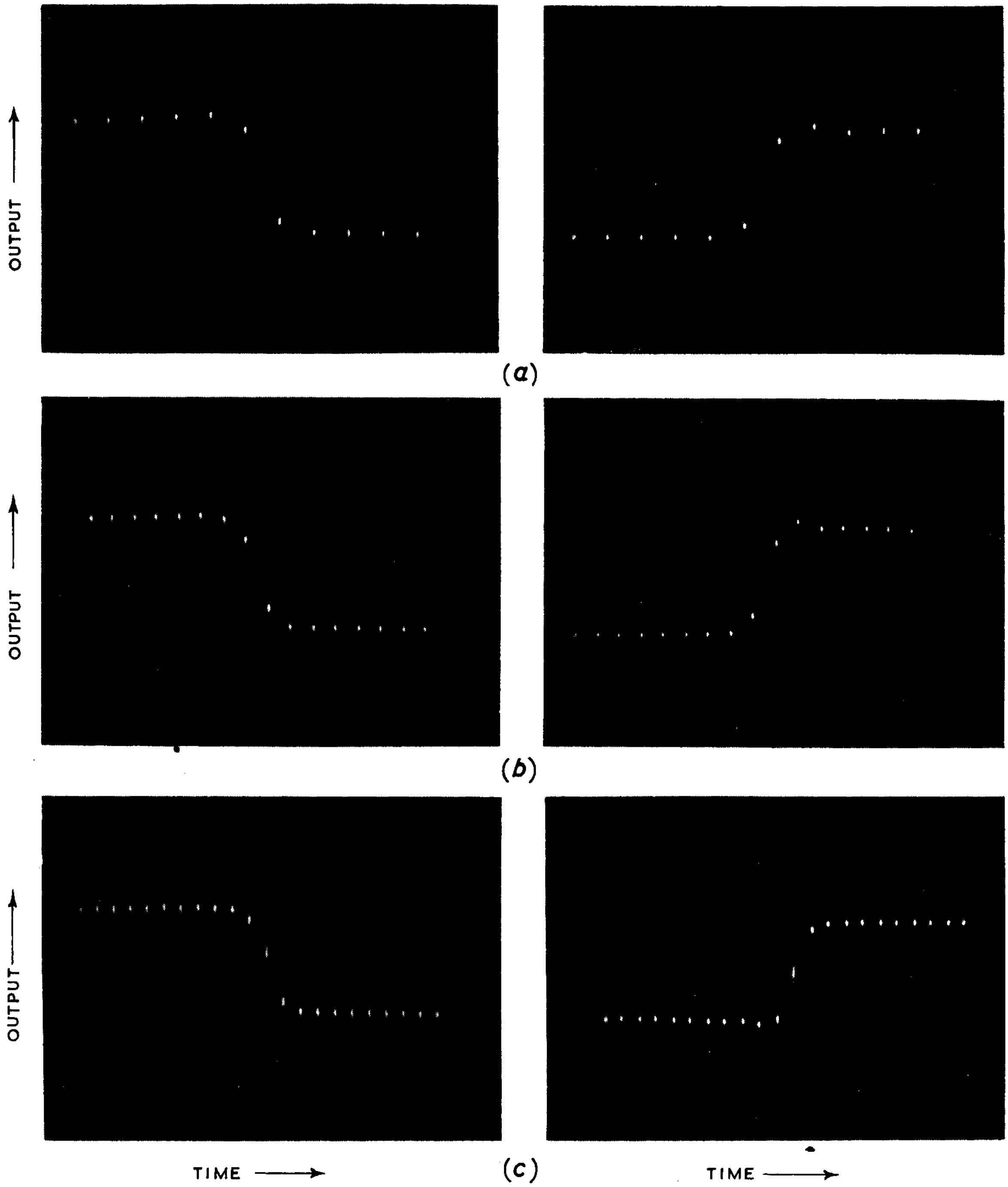

Fig. 7 - Vertical strobes of the edges of the test transparency using a 2μsec brightning pulse

(a) 405-line standard (b) 625-line standard (c) 819-line standard

From one point of view it is, of course, desirable that a tube be able to resolve a horizontal edge fully in one picture-line pitch of the particular standard used. This criterion is an arbitrary one, however, since such a resolution would lead to considerable 'interline flicker' on near-horizontal picture detail.

It will be seen from the results that, below approximately 300 active lines per picture height, the image orthicon satisfies this requirement. At the 405-line standard (377 active lines) the requirement is almost met since the resolution is then approximately 330 lines. At 625 lines (585 active lines) the performance is less satisfactory since the resolution has only improved slightly to approximately 360 lines. The potentially improved vertical resolution offered by this standard cannot, therefore, be fully realised. The resolution at the 819-line standard (737 active lines) is only approximately 385 lines and, therefore, nearly two picture lines are required for the reproduction of a horizontal transition.

Field-strobe photographs of black-to-white and white-to-black transitions at various line standards are shown in Figs. 7(a), 7(b) and 7(c) (signals from both the odd and even fields are shown). These illustrate clearly the progressive reduction in the performance of the tube in relation to the potentialities of the scanning standard.

A detailed examination of the shape of the edge transition was carried out at three standards: 405, 625, 819 lines. The graphs of these measurements are shown in Figs. 8 to 10; in each case the output for white has been normalised to unity. The rise times of the curves in Figs. 8 and 9 agree reasonably well with previous measurements. In the case of the 819-line measurement, Fig. 10, however, there is some disagreement that probably results from a small focusing error; nevertheless, the curve is reasonably representative of the performance of a tube on this standard. The general shape of all three curves is similar and not appreciably dependent on scanning standard (see conclusion to Appendix), but small differences exist between black-to-white transitions and white-to-black transitions. The more pronounced overshoot in the black-to-white transition has already been mentioned. In addition, in the case of the black-to-white transition, the 0% to 10% section of the transition extends for approximately 2·75 parts in 10^3 of picture height while the corresponding section in the case of the white-to-black transition extends for only 1·75 parts in 10^3 of picture height. The reasons for this are not understood.

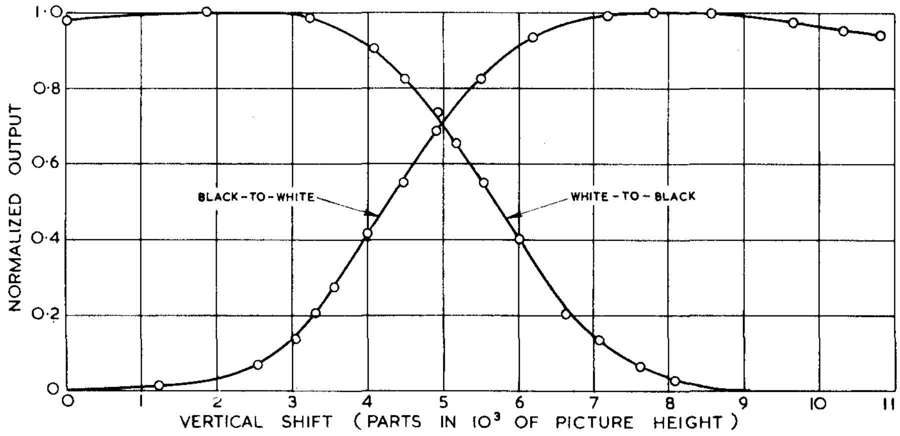

Fig. 8 - Detail of vertical resolution - 405-line standard

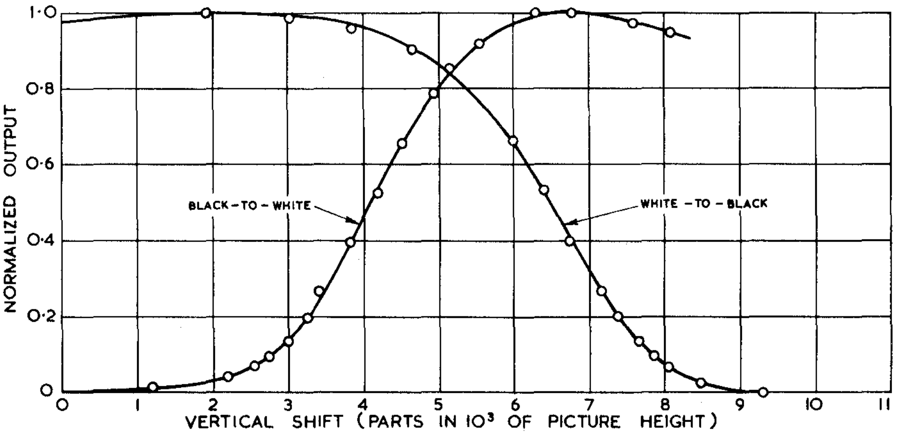

Fig. 9 - Detail of vertical resolution - 625-line standard

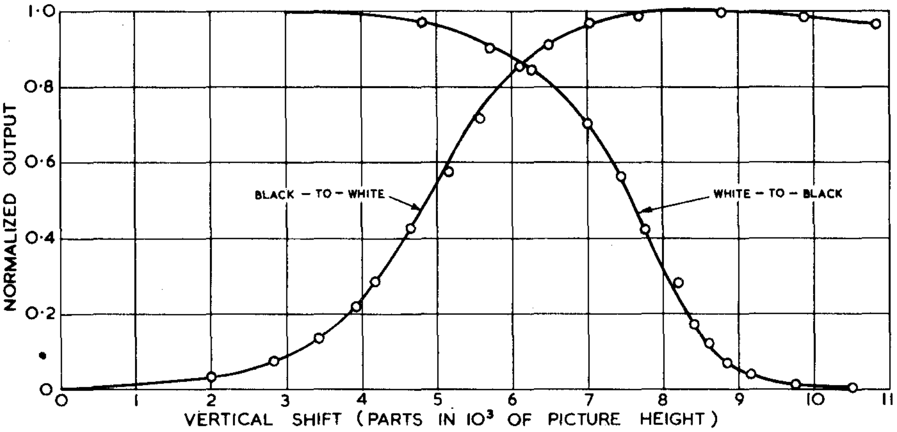

Fig. 10 - Detail of vertical resolution - 819-line standard

All the measurements so far described were made using 50 fields per second. Measurements were then made using the 525-line 60-field standard and two 50-field standards (405 lines and 625 lines); measurements on the two latter standards were repeated in order to eliminate any effects on the resolution such as 'burning' of the target. The results of the measurements for the two tubes are given in Tables 5 and 6.

TABLE 5

Vertical resolution using three scanning standards: Tube 'A'

SCANNING STANDARD		RESOLUTION	
SCANNING STANDARD (LINES PER PICTURE)	FIELDS PER SECOND	IN TERMS OF A FRACTION OF THE PICTURE HEIGHT	IN TERMS OF AN EFFECTIVE NUMBER OF LINES
405	50	$3{\cdot}1 \,.\, 10^{-3}$	323
525	60	$2{\cdot}36 \,.\, 10^{-3}$	424
625	50	$2{\cdot}58 \,.\, 10^{-3}$	388

TABLE 6

Vertical resolution using three scanning standards: Tube 'B'

SCANNING STANDARD		RESOLUTION	
SCANNING STANDARD (LINES PER PICTURE)	FIELDS PER SECOND	IN TERMS OF A FRACTION OF THE PICTURE HEIGHT	IN TERMS OF AN EFFECTIVE NUMBER OF LINES
405	50	$2{\cdot}64 \,.\, 10^{-3}$	379
525	60	$2{\cdot}50 \,.\, 10^{-3}$	400
625	50	$2{\cdot}38 \,.\, 10^{-3}$	420

It will be seen that, in both cases, the resolution using the 525-line standard is better than that obtained on the 405-line standard. The resolution, with the 625-line standard, of one tube is better than that obtained with the 525-line standard, and that of the other tube is worse; it may be concluded from this that tube performance with 525 lines is more nearly comparable with the performance with 625 lines than with 405 lines.

8. VARIATION OF VERTICAL RESOLUTION WITH LINE SPACING AND LINE-SCAN VELOCITY

8.1. Line Spacing

These measurements were made using the 405-line standard, the change of line spacing being effected by adjustment of the field-scan amplitude.

Vertical resolution was measured, at four different line spacings, as the average value of the resolution for the black-to-white and white-to-black transitions of the transparency.

The results of the measurements are given in Table 7 and in the lower curve of Fig. 11.

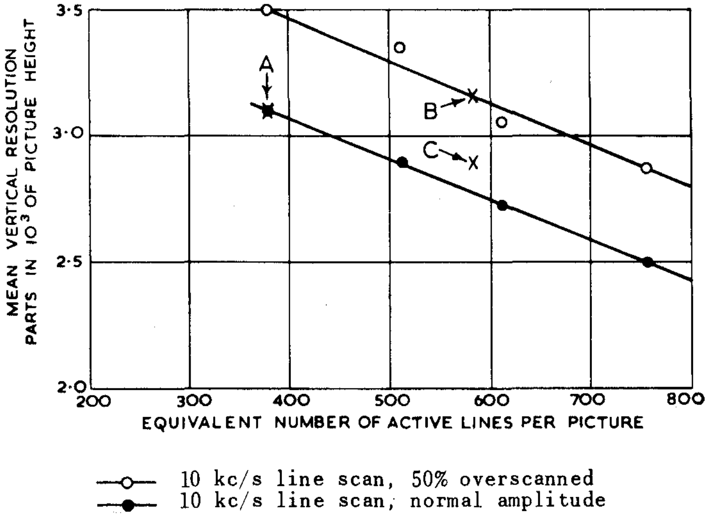

Fig. 11 - Variation of vertical resolution with line spacing and line-scan velocity

Point A Normal 405-line standard
Point B Simulated 625-line standard
Point C Normal 625-line standard
(15 kc/s line-scan frequency)

TABLE 7

Variation of vertical resolution with line spacing (Line-scan velocity normal)

EQUIVALENT NUMBER OF ACTIVE LINES PER PICTURE	VERTICAL RESOLUTION IN TERMS OF A FRACTION OF PICTURE HEIGHT (PARTS IN 10^3)		
	BLACK-TO-WHITE TRANSITION	WHITE-TO-BLACK TRANSITION	MEAN
377	3·0	3·2	3·1
510	3·0	2·8	2·9
610	2·6	2·85	2·73
754	2·4	2·6	2·5

It will be seen that only a small improvement takes place as the spacing between lines is reduced, all other variables being kept constant. This results from the fact that there is appreciable overlapping of the consecutive lines of a field, even with the 405-line standard, and the degree of overlap becomes greater as the lines become more closely spaced. Only that part of a line which does not overlap the previous line has a significant effect on vertical resolution; this is considered in a more quantitative way in the Appendix.

8.2. Line-scan velocity

In order to investigate the effect of line-scan velocity upon vertical resolution, the line-scan amplitude was increased by 50% and the previous set of measurements repeated.

The results of these measurements are given in Table 8 and in the upper curve of Fig. 11.

TABLE 8

Variation of vertical resolution with line spacing (Line-scan velocity increased)

EQUIVALENT NUMBER OF ACTIVE LINES PER PICTURE	VERTICAL RESOLUTION IN TERMS OF A FRACTION OF PICTURE HEIGHT (PARTS IN 10^3)		
	BLACK-TO-WHITE TRANSITION	WHITE-TO-BLACK TRANSITION	MEAN
377	3·54	3·45	3·5
510	3·5	3·2	3·35
610	2·87	3·22	3·05
754	2·7	2·95	2·87

It will be seen that increasing the line-scan velocity by 50% reduces the vertical resolution for all line spacings, the change with 377 active lines per picture height being from $3{\cdot}1 \,.\, 10^{-3}$ (Table 7) to $3{\cdot}5 \,.\, 10^{-3}$ (Table 8) of picture height. It has been shown[4] that the higher the scanning-spot velocity, the less is the efficiency of erasure. Calculations have shown that the discharge efficiency is somewhat less for the 'skirt' of the beam profile than for the centre. The effect on the vertical resolution is rather complicated. The area over which one line scan of the beam deposits charge may be considered as the sum of three strips; these are:

(i) that part which overlaps the area covered by the previous line scan of the same field;

(ii) that part which does not overlap any other line of the same field; the discharge efficiency is high over this area because the spot has its maximum dimension in the direction of line scan;

and

(iii) that part which is overlapped by part of the succeeding line of the same field.

Under normal conditions the first part makes the smallest contribution to the output when scanning a uniformly charged area of the target.

For two consecutive lines, A and B, of the raster an increase in the line-scan velocity results in the following effects:

Along strip (iii) of line A the beam deposits less charge, causing less change in target potential.

Immediately before scanning by line B the potential on strip (i) of line B, that is strip (iii) of line A, is higher because less charge has been deposited; the potentials on strips (ii) and (iii) of line B are also slightly higher because of the reduction in the electrostatic field due to charge on strip (iii) of line A, but the effect is less.

There are two opposing influences on the discharge efficiency during line B; the higher velocity reduces the discharge efficiency, but the higher initial potential raises the efficiency, particularly on strip (i).

As a result the output from line B may include almost as large a contribution from strip (i) as it does from strip (ii); hence, the effective width of the line is increased, degrading the vertical resolution.

8.3. Effects of simultaneous changes in line spacing and line-scan velocity

It might be expected that 625-line scanning conditions could be simulated by means of a modified 405-line scanning raster; an increase of the line-scan amplitude in the ratio of 81 to 52 would result in a line-scan velocity equal to that used for 625-line scanning and a reduction of the field-scan amplitude in the ratio of 377 to

585 would cause the line spacing to correspond to 625-line scanning conditions. It will be seen from Fig. 11, however, that there is no significant difference in the resolutions obtained using, on the one hand, the 405-line standard (Point A) and, on the other hand, the simulated 625-line standard (Point B) (the resolutions being $3{\cdot}10 \,.\, 10^{-3}$ and $3{\cdot}15 \,.\, 10^{-3}$ of picture height). However, it will be seen from Figs. 6 and 10 that an improvement of approximately 15% in vertical resolution is produced by a change from 405-line scanning to genuine 625-line scanning; the difference is small and is believed to be due to the difference in line-scan frequency.

Successive points of the vertical strobe display represent the outputs from elements of the target that are adjacent in the field direction. In the intervals between the scanning of such elements there are movements of charge in the target. Because the leakage between elements depends on the potential gradient it is most significant at the edges of sharply defined areas of high charge density and at the boundary between the scanned and unscanned parts of charged areas. During the line period preceding the scanning of an element, charge flows from that element to the adjacent elements of the previous line. This leakage of charge, which is dependent on the line-scan frequency, reduces the potential which exists at an element just before it is scanned, and so reduces the output signal. The effect on the 'toe' of the profile of a transition is small, but there is a significant reduction of output at the 'knee' of the transition; the fact that the reduction in level is more marked at higher signal levels increases the distance through which a scanning line must be shifted in order to change the output from 10% to 90% of maximum. The only other differences between the real and the simulated 625-line rasters arise because the simulation leaves some unscanned target areas above and below the picture and over-scanning occurs at the sides on to the target supports; neither of these effects is thought to have any significant effect on vertical resolution.

9. CONCLUSIONS

The best vertical and horizontal resolution is found to occur at very nearly the same beam focus conditions, indicating very little astigmatism in the scanning spot.

For scanning standards of 405 lines per picture and above, vertical resolution is found to be almost independent of the scanning standard used. On the 405-line standard (377 active lines), the resolution is approximately $3{\cdot}10^{-3}$ of picture height i.e., a transition requires only 1·1 lines for its portrayal. The upper limit of resolution is about $2{\cdot}5 \,.\, 10^{-3}$ of picture height; this is reached when a scanning standard employing 500 lines or more is used. The change in standard from 405 lines to 625 lines, therefore, results in an improvement in vertical resolution of only about one sixth. It may be concluded that should it be desirable to make full use of the improved vertical resolution offered by a 625-line standard, there is a need for improvement in the performance of the 4½ in. image orthicon, since, at the present time, a transition on this standard requires 1·6 lines for its portrayal. Such an improvement may not be found entirely desirable, however, since it would inevitably lead to the production of more disturbing patterns and flicker effects between the scanning lines and repetitive horizontal picture detail.

10. REFERENCES

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3. 'A Test Bench for 4½ in. Image Orthicons', Research Department Technical Memorandum No. T-1045.

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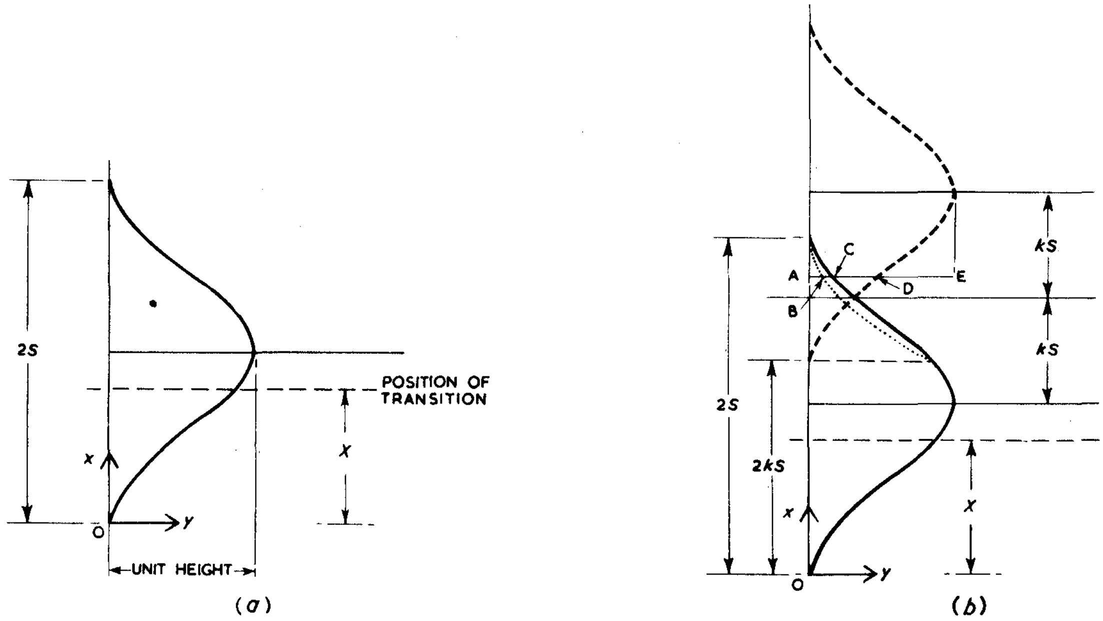
APPENDIX

The 'Profile' of the Beam

The scanning beam is not uniform in either density or width so the centre of a scanned line traced out by the beam is more effectively discharged than the edges of the line. In this appendix the 'beam profile' is taken as the curve whose vertical co-ordinate represents vertical distance from the centre of a scanning line and whose horizontal co-ordinate represents the proportion of the charge on the target which will be discharged by that part of the beam. If it were possible to plot a 'beam profile' which was virtually independent of picture content it could be used to calculate the erasure characteristic and the vertical resolution of the tube for different line spacings. In fact, the ability of the beam to discharge the target is known to depend on the potential of the target immediately before discharge[4] so the profile varies with changes of picture content. Nevertheless, an approximate approach gives an insight into some of the factors affecting vertical resolution and gives some indication of the size of the scanning spot.



(*a*) (*b*)

Fig. 12 - Beam profile

(a) Assumed profile of a single line
(b) Overlapping lines

—— Basic profile of line under consideration
········ Modification of line under consideration by the previous line
- - - - - Profile of previous line

The 'beam profile' has been assumed to be a 'raised-cosine' in shape, as shown in Figs. 12(a) and 12(b), and the scanning beam aperture to have a diameter of 2S. This particular shape of curve was chosen to represent the profile because it is of roughly the right shape and it is mathematically simple. The figures also describe a black-to-white transition in the scene. The output from a scanning line will be calculated for various relative positions of the scanning line and the transition assuming various degrees of overlap of consecutive lines of a field.

The Output from a Black-to-White Transition when there is no Overlapping of Consecutive Lines

Let the bottom edge of the spot be a distance X below the transition. The shape of the profile curve is

$$y = \tfrac{1}{2}\left(1 - \cos\pi \cdot \frac{x}{S}\right)$$

and the signal output σ is proportional to the area of that part of the white portion of the scene which overlaps the spot profile

$$\text{Then } \sigma \propto \int_0^X y \, dx$$

$$\text{Now } \int_0^X y \, dx = \tfrac{1}{2}\int_0^X \left(1 - \cos\pi\frac{x}{S}\right) dx$$

$$= \tfrac{1}{2}\left[X - \frac{S}{\pi} \cdot \sin\pi\frac{X}{S}\right]$$

When $X = 2S$, this becomes

$$\int_0^{2S} y \, dx = \tfrac{1}{2}\left[2S - \frac{S}{\pi}\sin 2\pi\right]$$

$$= S$$

$$\text{hence } \sigma \propto S$$

The output, relative to S, varies from zero to unity as shown in Table 9 and Fig. 13.

To find the shift in X required to make the output change from 10% to 90% of maximum let us suppose that the 10% point is at $x = X'$. From the symmetry of the curve the distance required is $2(S - X')$.

The equation to be solved is

$$\tfrac{1}{2}\left[X' - \frac{S}{\pi} \cdot \sin\pi \cdot \frac{X'}{S}\right] = \frac{1}{10} \cdot S$$

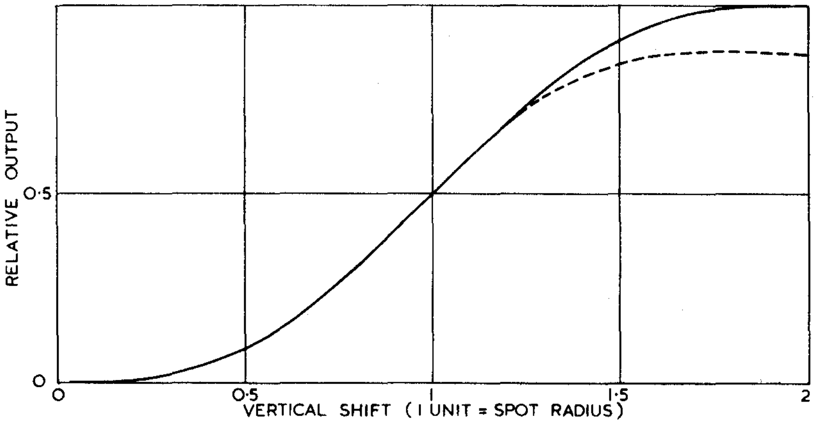


Fig. 13 - Theoretical vertical resolution: black-to-white transition

—— No overlap of scanning lines
---- All points scanned twice per field none scanned three times

By making successive approximations it is found that $X' \simeq 0{\cdot}52S$. Therefore, the 'rise' distance is

$$2\ [S - X'] = 0{\cdot}96S$$

This means that, if the lines of a field do not overlap, the reproduction of the transition takes 0·96 of the spacing between lines of the picture.

Similar results apply to a white-to-black transition, where the output would have been

$$\sigma \propto \int_X^{2S} y\,.\,\mathrm{d}x$$

$$\text{Now} \int_X^{2S} y\,.\,\mathrm{d}x = \tfrac{1}{2}\int_X^{2S} \left(1 - \cos\pi\frac{x}{S}\right)\mathrm{d}x$$

$$\text{Whence } \sigma \propto \tfrac{1}{2}\left[2S - X + \sin\pi\frac{X}{S}\right]$$

This is shown in Table 9 and Fig. 14.

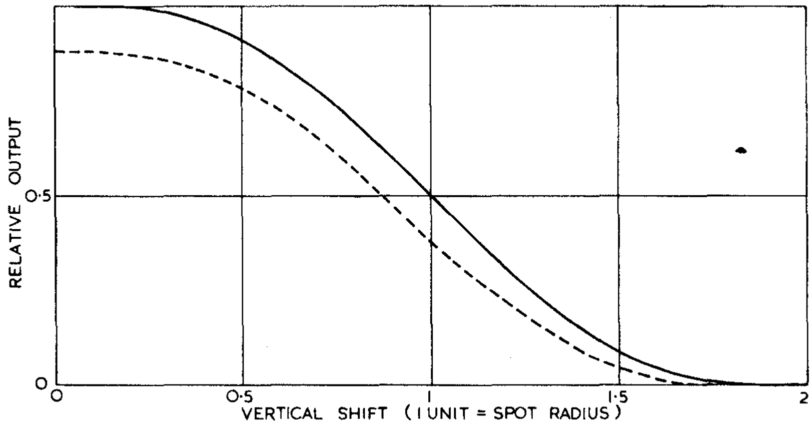


Fig. 14 - Theoretical vertical resolution: white-to-black transition

—— No overlap of scanning lines
---- All points scanned twice per field none scanned three times

The Outputs when Two Consecutive Lines of a Field Overlap, but no Point of the Target is scanned by Three Lines of one Field

Let the spot diameter again be $2S$ and let the picture-line pitch be kS, so that the lines of a field are spaced by $2kS$, where k lies between 0·5 and 1·0. This is shown in Fig. 12(b), in which

AE = maximum signal available at x = OA.

DE = signal left after previous line has scanned points for which x = OA.

AB = signal read off by line under consideration from point x = OA.

AC = signal which would have been read off if previous line had not overlapped.

The distance AB has been taken as $y' = (AC/AE)\,DE$.

Considering the black-to-white transition first, if X is less than $2kS$ the output, as before, is

$$\sigma \propto \tfrac{1}{2}\left[X - \frac{S}{\pi}\sin\frac{\pi}{S}\right]$$

If X lies between $2kS$ and $2S$ the output is

$$\sigma \propto \int_{0}^{2kS} y\,dx + \int_{2kS}^{X} y'\,dx$$

where y' is given by

$$y' = \tfrac{1}{4}\left[1 - \cos\frac{\pi x}{S}\right]\left[1 + \cos\frac{\pi(x - 2kS)}{S}\right]$$

The general case will not be considered further but the special case will be taken in which $k = 0{\cdot}5$, i.e. any closer line spacing would give three-fold overlap.

If $k = 0{\cdot}5$ then $2kS = S$

$$\text{Then} \int_{0}^{2kS} \tfrac{1}{2}\left(1 - \cos\pi\frac{x}{S}\right)dx = \tfrac{1}{2}S$$

$$\text{and} \int_{2kS}^{X} y'\,dx = \int_{S}^{X} \tfrac{1}{4}\left[1 - \cos\pi\frac{x}{S}\right]\left[1 + \cos\frac{\pi(x - S)}{S}\right]dx$$

$$= \frac{3}{8}(X - S) - \frac{S}{2\pi}\sin\frac{\pi X}{S} + \frac{S}{16\pi}\sin\frac{2\pi x}{S}$$

Adding these, the total output is

$$\sigma \propto \frac{3}{8}X + \frac{1}{8}S - \frac{S}{2\pi}\sin\frac{\pi X}{S} + \frac{S}{16\pi}\sin\frac{2\pi x}{S}$$

This is shown in Table 9 and Fig. 13.

Reading from this graph the rise from 10% to 90% takes a distance $0{\cdot}86S$ which is 1·72 of a picture line pitch.

Similar calculations for a white-to-black transition give the values tabulated in Table 9 and Fig. 14. The distance to fall from 90% to 10% of maximum output is $0{\cdot}92S$ of the picture line pitch.

The mean of the two is $\frac{1}{2}(0{\cdot}86S + 0{\cdot}92S) = 0{\cdot}89S$ or 1·78 of a picture line pitch.

TABLE 9

Theoretical responses to sharp transitions

$\frac{X}{S}$	NO OVERLAP OF SPOT		WITH OVERLAP, $k = 0{\cdot}5$	
	BLACK-WHITE	WHITE-BLACK	BLACK-WHITE	WHITE-BLACK
0	0	1	0	0·875
0·2	0·0065	0·993	0·0065	0·869
0·4	0·048	0·952	0·048	0·827
0·6	0·148	0·852	0·148	0·727
0·8	0·306	0·694	0·306	0·569
1·0	0·500	0·500	0·500	0·375
1·2	0·694	0·306	0·690	0·225
1·4	0·852	0·148	0·815	0·085
1·6	0·952	0·048	0·866	0·0085
1·8	0·993	0·0065	0·874	0
2·0	1·00	0	0·875	0

A COMPARISON BETWEEN CALCULATED AND MEASURED RESULTS

Measurements using the 405-line standard give a mean transition distance of a black-to-white transition of approximately $3{\cdot}05 \,.\, 10^{-3}$ of picture height. Calculations based on a spot which just fails to overlap in a field scan ($k = 1{\cdot}0$) gives a transition distance $0{\cdot}96S = 2{\cdot}54 \,.\, 10^{-3}$ of picture height while those based on complete two-fold overlap ($k = 0{\cdot}5$) gave a mean transition distance of $4{\cdot}72 \,.\, 10^{-3}$ of picture height.

Estimates made of the transition curve to be expected with a small overlap (k = 0·8, spot diameter approximately 4 . 10^{-3} of picture height) give an output of approximately the right transition distance and amplitude rising to 0·99 of the maximum signal available without overlap.

In the report on the discharge of the target[4] it was established that one scan of a uniformly charged area of the target deposited a negative charge which is approximately 75% of the original positive charge. Using the 'beam profile' method, if there were no overlapping of scan lines (k = 1·0) one scan would be estimated to remove 50% of the charge. With a small overlap (k = 0·8) this estimate would rise to about 50 x 0·99%/0·8 = 62%. The difference between this and the 75% quoted earlier would make a considerable difference to the signal produced by a second scan of the area without further illumination of the tube.

If, as was done in the previous investigations, we had considered a variation in line spacing while maintaining the same profile we would have predicted that when the spacing of lines in a field exceeded the spot diameter the output signal would be independent of line spacing. In practice the output was found to continue to rise as the line spacing was increased, showing that the skirt of the 'beam profile' curve is appreciably wider than expected.

The conclusions to be drawn from this attempt to estimate the profile of the beam, apart from the realisation that such a profile cannot be considered in quantitative terms but is only a general indication of the characteristics of the beam, are that the discharge efficiency of a scanning line is more uniform over a strip of width equal to line spacing than is indicated by a raised cosine curve. Most of the discharge takes place over a strip of width equal to 1¼ times line spacing and the spot has some influence over a strip of width equal to about three times the spacing of the lines of a field. Part of this skirt of the profile curve is due to the electrostatic field produced by the deposited charge, as discussed in Appendix 1 of reference 4.

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